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## **Endothermic salts integrated in impermeable suits do not reduce heat strain during exercise**

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### **Introduction**

Wearing impermeable garments during work inherently leads to heat strain, even in cold environments [1]. Phase change materials (mainly paraffin's or salt [4]) may be used as a thermal buffer (e.g. [2]) to reduce initial heat stress. Salts can also be used to absorb sweat, which may enhance the cooling power from the skin.

Recently, specific encapsulated salts utilising KSCN (potassium thiocyanate) have been developed that consume energy when the KSCN dissolves in water. The heat consumed when the KSCN (present inside 150 g of capsules containing 60% KSCN salt) dissolves in water is 22410 J (249 J/g \* 60% \* 150 g). When this solving takes place over a period of 30 minutes, the average power transfer is 12 W. One (1) g of KSCN-containing capsules absorbs close to 1 g of moisture. If we assume that 150 g sweat extra can be evaporated from the skin, this yields an extra cooling power of 182 W for 30 minutes. However this evaporated water from the skin is subsequently absorbed by the KSCN in the capsules. During this absorption from the gas phase, the condensation heat is released to the KSCN salt: about 182 W for 30 minutes. However, we hypothesise that this condensation heat will be partly transferred to the body and partly to the environment [3], providing a net benefit to the body.

Thus, the total cooling effect due to the salt capsules is composed of two parts:

- The cooling effect of about 12 W due to the heat consumption by the dissolving of the salts in water;
- The cooling effect of maximal 182 W, which equals the difference between the evaporative heat and the condensation heat. The latter is generated in the salt capsules that transfer part of the heat to the environment.

The overall cooling effect should therefore be in between 12 W and 194 W.

The purpose of our study was to test the efficacy of a KSCN-based absorbing salt as a PCM for use within impermeable protective clothing. We tested the PCM during 20 min of moderate exercise in a hot (35°C, 40% relative humidity) environment, and hypothesized that thermal strain would be lower in the PCM compared to the non-PCM condition.

### **Methods**

Nine males (age [mean (±SD)] 24 (4) y, height 181 (6) cm, body weight 78 (12) kg) participated in the study. The experiment was a repeated measures design, with each participant performing a session using the salts (S) and control (C) garments and the order of the experimental conditions

counter-balanced. The garment was a thin, air impermeable, synthetic coverall, complete with hood, weighing approximately 500 g without salts (Microgard Microchem 4000, Microgard, Kingston Upon Hull, United Kingdom). The garment was supplied in the specified size and the subjects were only wearing a slip underneath. The S garment had additional salt packages containing 30 g 60% KSCN salt packages at the back, two similar packages at the sides of the coverall, and two at the upper legs. The protocol was approved by the local TNO ethics committee.

Participants were weighed nude and dressed to an accuracy of 1 g (Sartorius F300S, Göttingen, Germany) just prior and after the 30 minutes heat exposure to determine sweating rate and evaporative rates, respectively. The subjects were instrumented with eight iButtons type DS 1922L (Maxim, San Jose, USA) according to ISO 9886 (ISO 9886 2004) and inserted a rectal probe (YSI 400 series, Yellow Springs, USA) prior to the experiment 10-12 cm beyond the anal sphincter. Instrumentation and suit donning occurred in a room of 30°C, where they stayed for about 5 minutes and then entered the climatic chamber (35°C, 40% relative humidity).

The experimental protocol consisted of 5 min of sitting, 20 min of cycling exercise at 2 W/kg body weight (Lode Excalibur, Lode, Groningen, The Netherlands), and another 5 minutes of sitting. Oxygen uptake was determined using open-circuit spirometry (Oxygon Pro, Carefusion, San Diego, US). Heart rate was monitored using telemetric sensors and transmitters (RS400, Polar Electro, Kempele, Finland). Five minute averages were calculated for all physiological variables. Rating of Perceived Exertion (RPE), thermal sensation (ISO 10551), and thermal comfort [2] were assessed every 5 minutes.

Analysis of variance was performed with participants as random independent factor and time (every 5 minute) and suit (with/without salt) as fixed independent factor (GLM module, Statistica version 8). The dependent variables were heart rate, rectal temperature, mean skin temperature, body weight loss, weight of the suit, thermal sensation, RPE and thermal comfort.

## Results

The C and S garments were different in weight (512 (14) g versus 793 (16) g) due to the salt within the S garment and the attachment materials. However, the extra weight of S did not result in a significantly higher metabolic cost of exercise, with no difference in oxygen uptake between C (2262 (150) mL·min<sup>-1</sup>) and S (2180 (315) mL·min<sup>-1</sup>).

The physiological and perceptual responses during the final 5 min period of the exercise using the C and S are presented in Table 1. Overall, no significant main effects or interactions were observed for any variable. Rectal temperature increased significantly and equally by 0.87 (0.26)°C and 1.01 (0.28)°C with C and S, respectively. No differences were observed in sweat rate or evaporation rate between C (0.97 [0.26] and 0.45 [0.16] L·h<sup>-1</sup>) and S (1.01 [0.26] and 0.51 [0.16] L·h<sup>-1</sup>). Importantly, even at the sites where the salt packages were directly in contact with the skin (chest, back and thighs), no beneficial effects of the salts in lowering local skin temperatures were evident.

**Table 1** . Results averaged over the nine subjects for the last five minute of exercise.  $T_{re}$  = rectal temperature,  $T_{sk}$  = mean skin temperature, RPE = rating of perceived exertion, TC = thermal comfort, TS = thermal sensation.

variable	unit	Control		Salts	
		Mean	Std.Dev.	Mean	Std.Dev.
Heart Rate	bpm	175.2	8.7	176.7	9.1
$T_{re}$	°C	38.1	0.3	38.1	0.3
$T_{sk}$	°C	37.9	0.3	38.2	0.3
$T_{forehead}$	°C	37.2	0.2	37.6	0.8
$T_{back}$	°C	38.0	0.3	38.3	0.2
$T_{chest}$	°C	38.1	0.5	38.3	0.3
Tupper arm	°C	38.0	0.3	38.2	0.4
Tlower arm	°C	37.8	0.4	38.0	0.4
$T_{hand}$	°C	36.7	0.6	36.9	0.5
$T_{thigh}$	°C	38.3	0.5	38.6	0.3
$T_{calf}$	°C	37.9	0.4	38.1	0.5
RPE		15.9	2.6	16.4	2.6
TC		3.1	1.2	3.4	1.2
TS		3.2	0.7	3.3	0.9

## Conclusions

Although humans have an excellent mechanism for heat dissipation through evaporation of sweat, this mechanism is seriously compromised during work in impermeable protective clothing, due to the inability for sweat to evaporate into water vapour and dissipate heat through the clothing. Phase change materials (PCMs) from ice through to multiple varieties of absorbent salts, may form an alternative due to their relatively lower level of complexity and weight, along with ease of replacement [4-6]. When the air space between undergarment and protective clothing is relatively dry, more sweat can evaporate from the skin, and more cooling power is generated on top of the PCM effect.

In this project we carefully evaluated which salts may provide optimal cooling. Unlike sodium sulphate, KSCN is an endothermic salt that will not generate heat when a phase change occurs. Moreover, it has the advantage that water vapour is absorbed and thus the water vapour content in the air space between the skin and the protective garment reduces. Therefore, evaporation of sweat should be enhanced and cooling should be improved. Even though the choice of salts and the exercise protocol were optimized to get cooling effects, in our study no benefits of the salts were observed. The added weight and volume may constitute an extra load of about 1-2% metabolic rate increase per kg [7], albeit invisible in oxygen uptake data. The assumption that extra sweat can evaporate due to a drier air space is probably not true. Even the skin locations just next to the salt pads showed no differences in temperature with the control suit.

We conclude that adding the endothermic salt KSCN in protective clothing does not lead to a reduction in heat strain during heavy work in the heat.

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## References

1. Rissanen S: **Quantification of thermal responses while wearing fully encapsulating protective clothing in warm and cold environments**. PhD thesis Oulu University, Finland 1998, .
2. Reinertsen RE, Færevik H, Holbø K, Nesbakken R, Reitan J, Røyset A, Suong Le Thi M: **Optimizing the performance of phase-change materials in personal protective clothing systems**. *Int J Occup Saf Ergon* 2008, **14**(1):43-53.
3. Havenith G, Richards MG, Wang X, Bröde P, Candas V, Den Hartog E, Holmér I, Kuklane K, Meinander H, Nocker W: **Apparent latent heat of evaporation from clothing: Attenuation and "heat pipe" effects**. *J Appl Physiol* 2008, **104**(1):142-149.
4. Mondal S: **Phase change materials for smart textiles - An overview**. *Appl Therm Eng* 2008, **28**(11-12):1536-1550.
5. Shim H, McCullough EA, Jones BW: **Using phase change materials in clothing**. *Text Res J* 2001, **71**(6):495-502.
6. Gao C, Kuklane K, Holmér I: **Cooling vests with phase change materials: The effects of melting temperature on heat strain alleviation in an extremely hot environment**. *Eur J Appl Physiol* 2011, **111**(6):1207-1216.
7. Dorman LE, Havenith G: **The effects of protective clothing on energy consumption during different activities**. *Eur J Appl Physiol* 2009, **105**(3):463-470.